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APPLICATION
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TITLE: DISTRIBUTING FORCES FOR ELECTRODEPOSITION

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DISTRIBUTING FORCES FOR ELECTRODEPOSITION

BACKGROUND

The present invention relates generally to electrodeposition and particularly to electrodeposition onto silicon wafers or other objects.

With large scale circuit integration comes a need for smaller features and increased circuit density. As component density increases, the surface space available to connect the components decreases. One solution to this "wiring" problem is to layer insulating materials and conductive materials. Generally, the conductive layers are connected by conductive vias or plugs formed through the insulating material.

The metal and insulating material used to interconnect device components may determine the overall device performance. For example, interconnect resistance (R) and capacitance (C), the RC constant, may be an indicator of circuit speed. For example, a high RC constant may indicate a slow circuit signal. Interconnecting components with metals having low resistivity may lower the RC value. Further, separating interconnects with a dielectric having a low dielectric constant may reduce capacitance, which would also lower the RC value. Thus, when resistivity and capacitance are both reduced, device performance may increase.

Aluminum and aluminum alloys have enjoyed widespread use to interconnect components in integrated circuits. However, aluminum may limit the speed of some circuits. Further, aluminum may be difficult to deposit in vias having small depth to width or aspect ratios. In contrast, copper has a lower resistance than aluminum, hence it is a better conductor. Thus, copper layered with a low capacitance dielectric may be well suited for smaller, faster integrated circuits. Copper use in integrated circuits however, is not without its own unique challenges. For example, copper is not easily patterned or

etched. Thus, copper deposition in vias and/or trenches that have been etched in a dielectric is one way to form copper interconnects and plugs.

Copper may be deposited on a wafer via chemical vapor deposition (CVD), plasma enhanced CVD, sputtering, and electrodeposition such as electroplating. Electroplating generally takes place at lower temperatures and at a lower cost than other deposition techniques. Further, electroplating is a favored deposition technique when using dielectrics having low dielectric constant.

To deposit a metal on a wafer via electrodeposition, the back surface of the wafer is sealed off and electrical contact is made with the front surface of the wafer. Sealing the back of the wafer off and establishing electrical contact with front of the wafer may require considerable force to be exerted on the wafer. As such, soft materials such as low dielectric insulators may be susceptible to damage.

Accordingly, there is a need for a way to deposit a conductive material without causing significant damage to the object that the conductive material is to be deposited on.

BRIEF DESCRIPTION OF THE DRAWING

Figure 1 is a cross section of a simplified system for electrodeposition;

Figure 2 is a bottom-up view of a portion of the system of Figure 1 according to some embodiments of the present invention;

Figure 3 is a cross section of the portion of the system of Figure 2;

Figure 4 is a cross section of an alternate embodiment of a portion of the system of Figure 1;

Figure 5 is a partial cross section of the portion of Figure 3 before electrical contact is made with an object to be electroplated;

Figure 6 is a partial cross section of the portion of Figure 3 when initial contact is made with the object to be electroplated; and

Figure 7 is a partial cross section of the portion of Figure 3 when electrical contact for deposition is made with the object to be electroplated.

DETAILED DESCRIPTION

Referring to Figure 1, an exemplary plating cell or system 10 for electrodeposition is shown in simplified form. Generally, a metal, metal alloy or other conductive material may be deposited on an object 12 while the object 12 is immersed in the plating cell 10. For example, in some embodiments, the object 12 may be a wafer. Thus, copper, gold, lead, nickel or alloys thereof may be deposited on the wafer 12 using system 10. The system 10 may include a container 14, an anode 16, a seal assembly 18, a frame 20, a base 22 and a power supply 24.

The container 14 may be any container for use in electrodeposition. As shown in Figure 1, the container 14 is box-like having sides 26 and a bottom 28, although embodiments of the present invention are not limited in this respect. The container 14 may also include a top (not shown). When in use, the container 14 may be filled with an electrolytic solution 32. In some embodiments, ions in the electrolyte 32 facilitate electroplating. Further, in some embodiments the anode 16 may add ions to the electrolytic solution 32. For example, the anode 16 may be disposed in the electrolyte 32 within container 14. Thus, when a voltage potential is applied to the anode 16 and the object 12 to be plated, ions may be released into the electrolyte 32 via an oxidation reaction. Generally, the anode 16 is a metal or combination of metals and may be a single piece or segmented, although embodiments are not limited in this respect.

The seal assembly 18 may also be disposed in the container 14. In some embodiments, the seal assembly 18 may include a thrust plate and/or a seal plate (not individually shown) having a flexible seal material or mechanism such as a sealing ring 30. In some embodiments, the sealing ring 30 may be positioned to contact the backside 36 of the wafer 12 to create a watertight seal to prevent deposition and/or contamination

on the wafer backside 36. For example, a force may be applied by the seal assembly 18 (force producing mechanism not shown) to the backside 36 of the wafer 12 while the base 22 supports the wafer 12 at the front side 36, holding the wafer 12 stationary. Thus, when the sealing force is applied, a watertight seal is create by the sealing ring 30. As such, conductive material is not deposited on the wafer backside 36.

During electrodeposition, the frame 20 and base 22 may oppose the seal assembly 18 to contact the front side 34 of the wafer 12. Generally, current is supplied to the wafer 12 through the frame 20. In contrast, there is no electrical connection between the base 22 and the wafer 12. Thus, the base 22 may serve as a support for the wafer 12 during surface sealing and/or electrodeposition.

The power supply 24 may connect the frame 20 and the anode 16. Generally, the power supply 24 delivers a positive voltage to the anode 16 and a negative voltage to the frame 20. In this way, when the wafer 12 and anode 16 are disposed in the electrolyte 32 an electric circuit may be completed from the wafer 12 to the anode 16.

When system 10 is in use, a conductive material such as copper may be deposited on the front side 34 of the wafer 12, although embodiments of the invention are not limited with respect to the conductive material or a wafer. Generally, to deposit a metal on a wafer 12 via electroplating, the wafer 12 front side 34 is pre-coated with a seed layer (not shown). For example, if copper is to be deposited, a seed layer of copper may be deposited over a barrier layer by physical vapor deposition (PVD) or high density plasma PVD although embodiments are not so limited. Further, the backside 36 of the wafer 12 may be sealed off to prevent deposition on other than the front side 34. The wafer 12, backside seal assembly 18, frame 20 and base 22, or portions thereof may be immersed in the electrolytic solution 32 including ions of the metal (e.g., Cu^{2+}) to be deposited.

While in solution 32, the wafer 12 front side 34 may be electrically connected to the power supply 24 via the frame 20. The anode 16 may also be electrically connected to

the supply 24. Thus, when an electric potential is applied, metal ions from the electrolytic solution 32 may be reduced at the wafer 12 front side 34 to deposit the conductive material, although embodiments are not limited in this respect. Further, oxidation at the anode 16 may replenish the supply of metal ions in the electrolyte 32. Thus, in some embodiments, the system 10 may be utilized to deposit copper in vias and/or trenches on a wafer 12 front side 34 to form plugs and interconnects respectively. Overfill of the conductive material during electrodeposition may be removed by chemical mechanical polishing (CMP) or any other suitable removal technique.

Referring to Figures 2 and 3, details of the frame 20 and base 22 are shown. With respect to Figure 2, the frame 20 and base 22 are devoid of a coating 48 to better illustrate the frame 20 and base 22 in this view. Further, although not shown, the frame 20 and base 22 may be independently attached to a robot. In this way, in some embodiments the frame 20 and base 22 are not connected, which may enable independent movement.

In some embodiments, the frame 20 may be circular and may include a circular inner portion 42 that defines an aperture. However, the frame 20 may be any shape such as a square, rectangle, pentagon, octagon and the like. One or more flexible or spring-like beams 38 may be connected to and extend from the frame inner portion 42. For example, the individual spring-like beams 38 may have a first end 44 and a second end 46. The beam 38 may be joined to the frame 20 at the first end 44 to project inwardly from the frame inner portion 42. Further, the second end 44 may terminate with a contact point or pad 40. The points 40 may be configured to minimize localized areas of high pressure on the front side 34 of the wafer 12. As shown in Figure 2, there are eight beams 38, each associated with a contact pad 40. However, embodiments are not limited with respect to the number of beams 38.

The contacts 40 and beams 38 may provide electrical contact to the wafer 12. For example, the frame 20, beams 38 and pads 40 may be a conductive metal such as stainless

steel as one example, although embodiments are not so limited. However, the frame 20 and beams 38 may be coated with a soft, chemically resistant material 48 such as KALREZ of Dupont Dow Elastomers as one example. In some embodiments, the beams 38 may be independently coated to preserve resiliency. Generally, only a portion of each contact pad 40 is coated with the material 48. For example, the surface 50 of the points 40 lack the coating 48. In this way, the surface 50 may electrically contact the wafer 12. The coating 48 on the pads 40 may be continuous with the coating 48 on the beams 38 in some embodiments of the present invention. Thus, there are many ways to coat the frame 20, beams 38 and pads 40 and embodiments of the present invention are not limited in this respect.

Still referring to Figures 2 and 3, the base 22 may also be annular having an inner portion 52 that defines an annular aperture. However, like the frame 20, the base 22 may be any shape and the inner portion 52 may define an aperture of complementary shape. Further, in some embodiments, the base inner portion 52 may be serpentine, have "V's", or the like. The shape of the base 22 and/or inner portion 52 may complement the shape of the wafer 12 and/or the frame 20 although embodiments of the invention are not so limited.

The wafer 12 may be uniformly seated on the base inner portion 52. For example, the base 22 may be a strong metal such as stainless steel or titanium, as a few examples. Further, the base 22 may be coated with the material 48. Referring to Figure 3, in some embodiments, the wafer 12 may be seated on the material 48 that covers the top surface 56 of the base inner portion 52. However, as shown in Figure 4, the base inner portion 52 may be bent toward the wafer 12. As such, the wafer 12 may be seated on or be supported by the material 48 that covers the end portion 54 of the base inner portion 52.

The region of the base inner portion 52 (e.g., coated surface 56 or end portion 54) that supports the wafer 12 may substantially continuously contact the wafer front side 34

to uniformly seat the wafer 12 thereon. That is, in some embodiments the support region may make continuous contact with the periphery of the wafer 12. Alternately, in other embodiments continuous contact with the wafer 12 may be interrupted. For example, the base 22 may have elevated surfaces that contact the wafer 12 at is periphery. Either way, the force required for sealing may be distributed about the periphery of the wafer 12 by the base inner portion 52. In those embodiments including interrupted contact, it is preferable to have the maximal amount of base 22 surface area (coated or uncoated) contacting the wafer 12. In this way, the force required for sealing may be distributed about the wafer 12 periphery without creating localized areas of high pressure that could damage the wafer 12.

Damage to the wafer 12 front side 34 may be reduced or eliminated by controlling the amount of force each contact pad 40 places on the wafer 12 front side 34. Controlling the amount of force may be influenced by beam 38 design. For example, each beam 38 may be spring-like or flexible and may independently deflect relative to the wafer 12 front side 34. That is, each beam 38 may approximate a cantilevered beam with an end load. Thus, the force supported on the beam 38 end or pad 40 may be calculated according to equation 1.

$$F'' = \frac{-3dEI}{L^3} \qquad \text{(Equation 1)}$$

where F" (Figure 7) is the supported force, d is the displacement of the contact 40, E is the Modulus of Elasticity, I is the Moment of inertia of a cross-sectional area, and L is the length of the beam 38. Thus, when working with materials with low mechanical strength the beams 38 and/or pads 40 may be designed to deliver a force that will enable electrical contact for deposition yet not exceed the mechanical strength of the front side 34, including a front side 34 having one or more films disposed thereon.

Referring to Figures 3 and 4, beams 38 may vary in design, as determined by the calculated force. For example, in some embodiments beams 38 may be a reduced

thickness as compared to frame 20. Further, beams 38 may be straight, bent, curved or any other configuration. As shown in Figure 3, the beams 38 may be relatively long. As such, the pads 40 may contact the wafer 12 inward of the base 22. For example, the wafer 12 may have a given diameter "D". In some embodiments, the contacts 40 may touch the wafer 12 at a diameter that is about D-1.5 millimeters (mm) and the base 22 may touch the wafer 12 at a diameter of about D-0.9 mm. Thus, opposing pads 40 are closer to each other than opposing portion of the base 22. Nevertheless, the front side 34 to be deposited upon is within the openings defined by the base 22 and the contacts 40.

As shown in Figure 4, in some embodiments the length of the beams 38 may be relatively short. As such, the distance between opposing base inner portions 52 is less than the distance between opposing pads 40. However, the distance between opposing base inner portions 52 should still define an area that will permit deposition on all desired surfaces of the wafer 12.

Referring to Figure 5, when in use, the wafer 12 may initially rest only on the base 22. For example, the wafer 12 may rest on the surface 56 or end 54 (Figure 4) of the base inner portion 52. As such, front side 34 of the wafer 12 may be exposed. The frame 20 may be in a plane generally parallel to the plane of the base 22 without contacting the wafer 12. As such, there may be a gap "g" between the wafer front side 34 and the contact pads 40.

In some embodiments, the surface seal may be established before the contact points 40 make electrical contact with the wafer 12. For example, the seal material 30 may contact the backside 36 of the wafer 12 via the seal assembly 18. A force "F" may be applied to the backside 36 of the wafer 12, which is held stationary by the base 22. A resultant counterforce "F'" may be applied to the front side 34 of the wafer 12 by the base 22. The pressure on the front of the wafer 12 is distributed over the interface between the

wafer 12 and the base 22. Thus, damage to the front side 34 of the wafer 12 is minimized or eliminated during sealing.

Referring to Figure 6, reducing the gap "g" enables initial contact between wafer front side 34 and the contact pads 40. There is little, if any force associated with initial contact between the wafer 12 and pad 40. To enable initial wafer 12 and pad 40 contact, the frame 20 may be independently moved toward the base 22. Alternately, the base 22, wafer 12 and seal assembly 18 may be moved toward the contacts 40, stopping with initial contact between the wafer 12 and contact pads 40. In yet other embodiments, both the frame 20 and base 22 may be moved independently toward each other until initial contact between the points 40 and wafer front side 34 is made without substantial force.

Referring to Figure 7, electrical contact for electrodeposition may be made by continuing to move the frame 20 and/or base 22 as described above. However, as electrical contact is made, the wafer 12 and contact pads 40 may press against each other to deflect the beams 38 downward a distance "d" relative to the wafer front side 34. Because the beams 38 and/or pads 40 have been designed to exert a calculated or predicted force on the wafer front side 34, damage to the wafer 12 front side 34 is minimal if at all. In other words, the force F" exerted by the contacts 40 for the displacement of a particular beam 38 may be predicted such that the mechanical strength of the wafer 12 and/or films disposed thereon is not exceeded.

While the present invention has been described with respect to a limited number of embodiments, those skilled in the art, having the benefit of this disclosure, will appreciate numerous modifications and variations therefrom. It is intended that the appended claims cover all such modifications and variations as fall within the true spirit and scope of this present invention.